Hydrodynamic modeling of extremely cooling winds of Super Star Clusters

(R. Wünsch, J. Palouš, G. Tenorio-Tagle, S. Silich, C. Muñoz-Tuñon)

Super star clusters:

- masses: $M_{\rm SC} \sim 10^5$–10^7 $M_\odot$
- radii: $R_{\rm SC} \sim 1 - 5$ pc
  $\rightarrow$ very compact
- age: up to few Myr
- $L_{\rm mech} \sim 10^{39} - 10^{42}$ erg/s
- stars return $\sim 30\% M_{\rm SC}$ back into ISM
- recombination lines $\sim 30 - 70$ km/s

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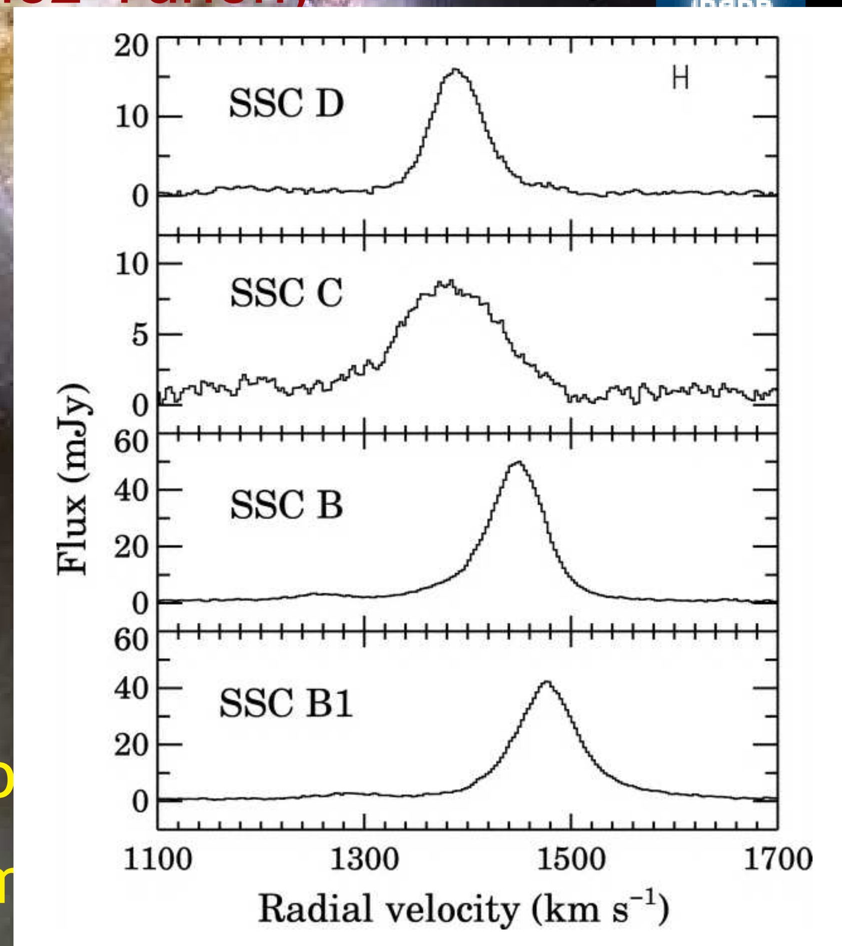
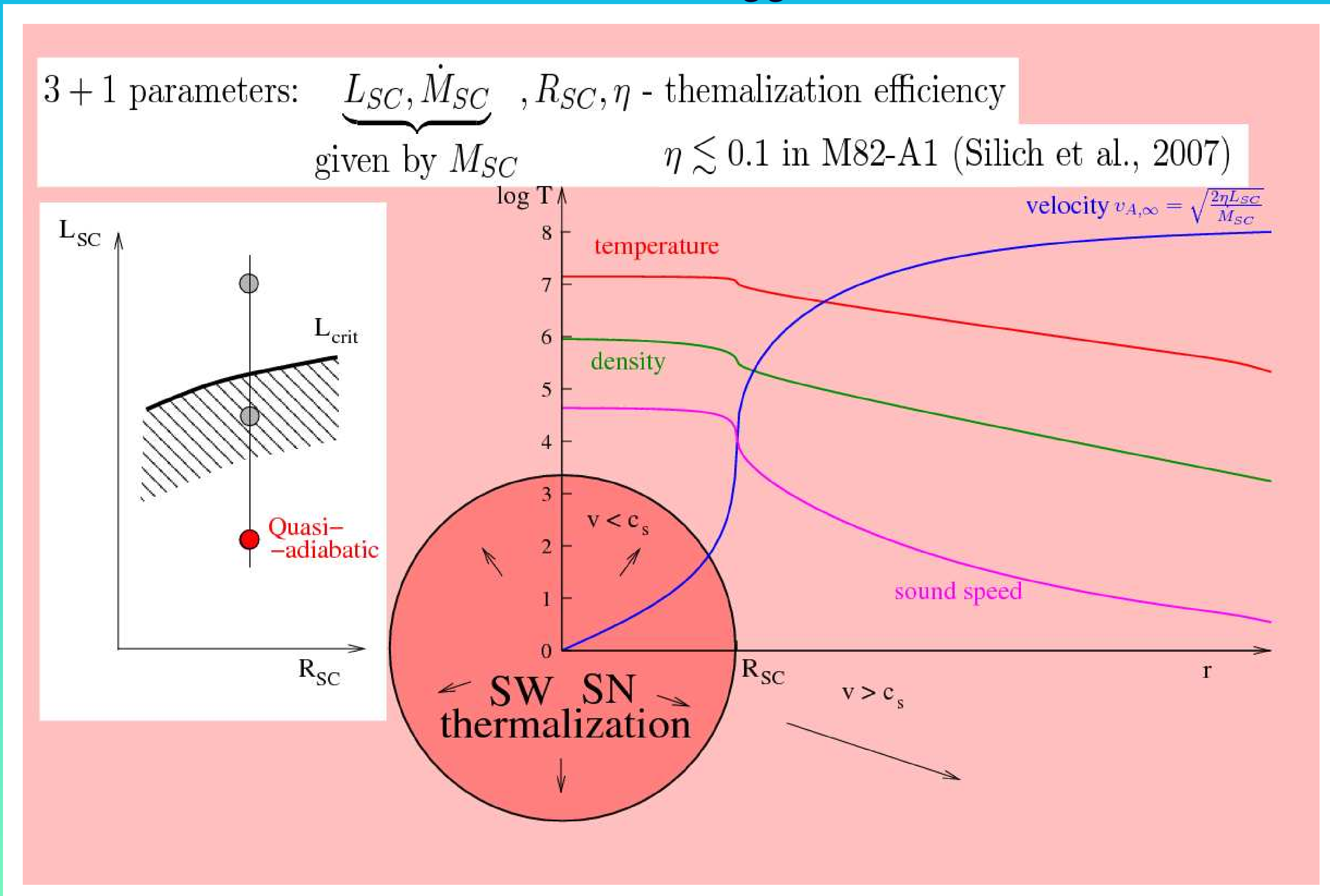


Gilbert & Graham (2007)

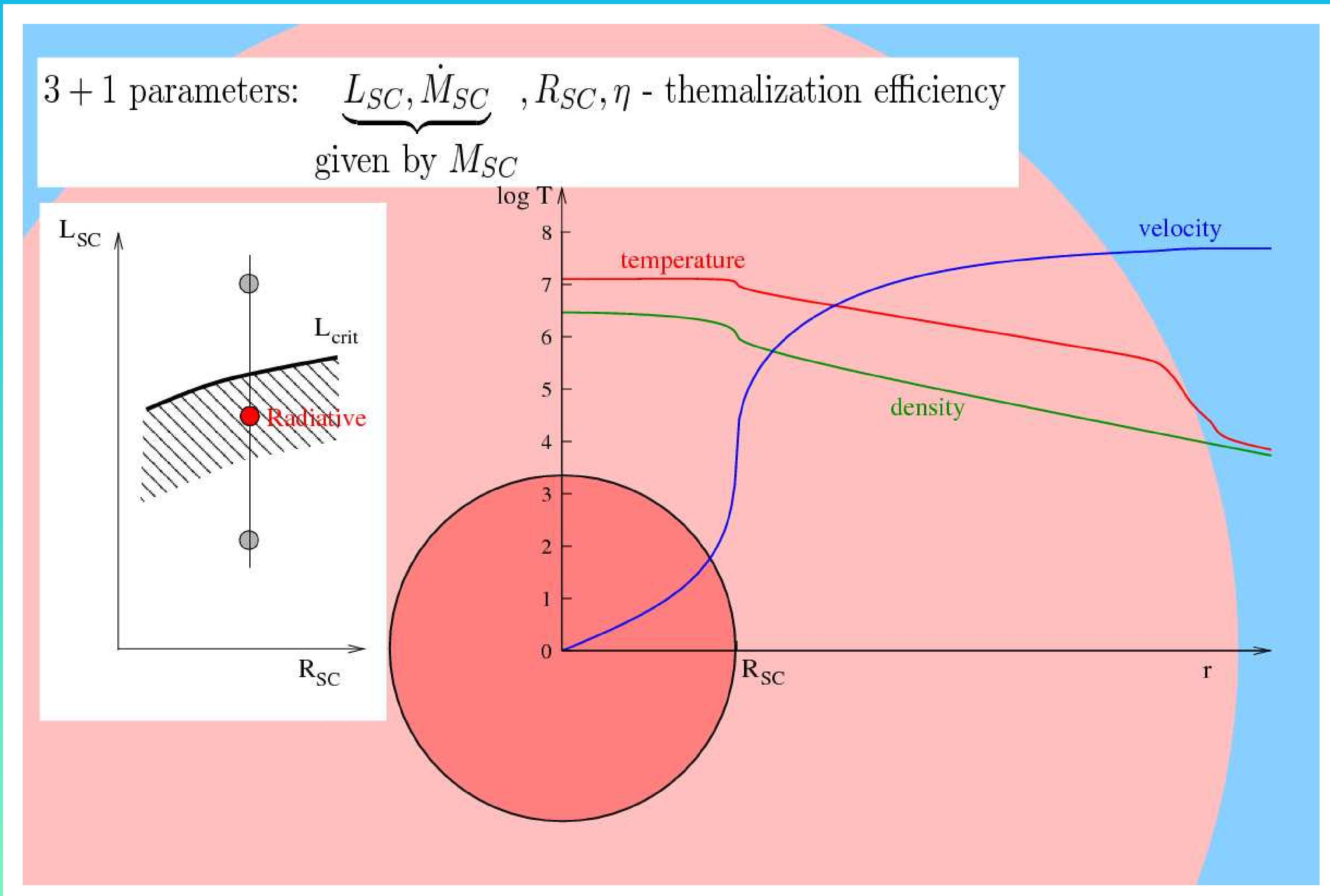
Physical model

Chevalier & Clegg (1985)



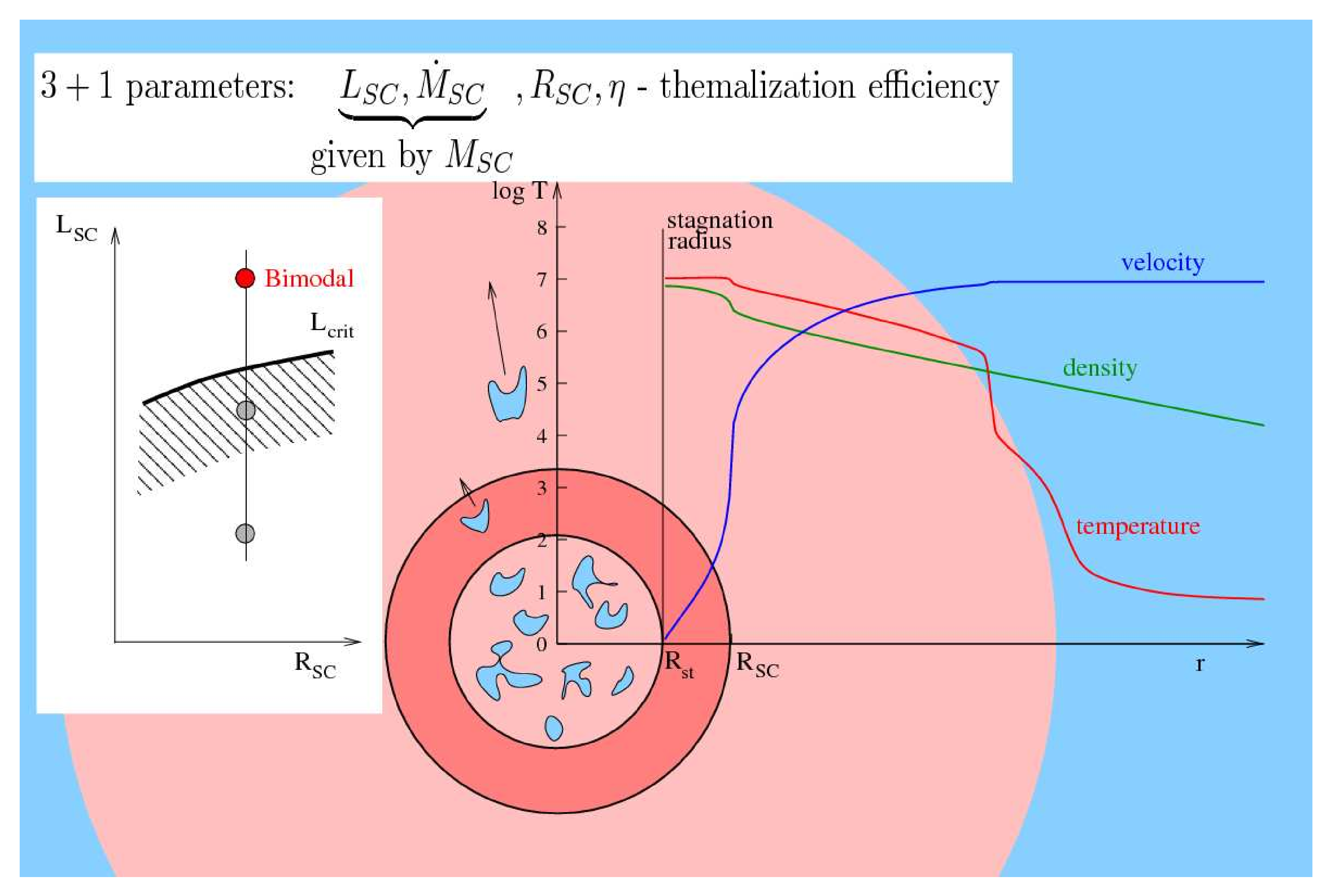
Physical model

Silich et al. (2004)

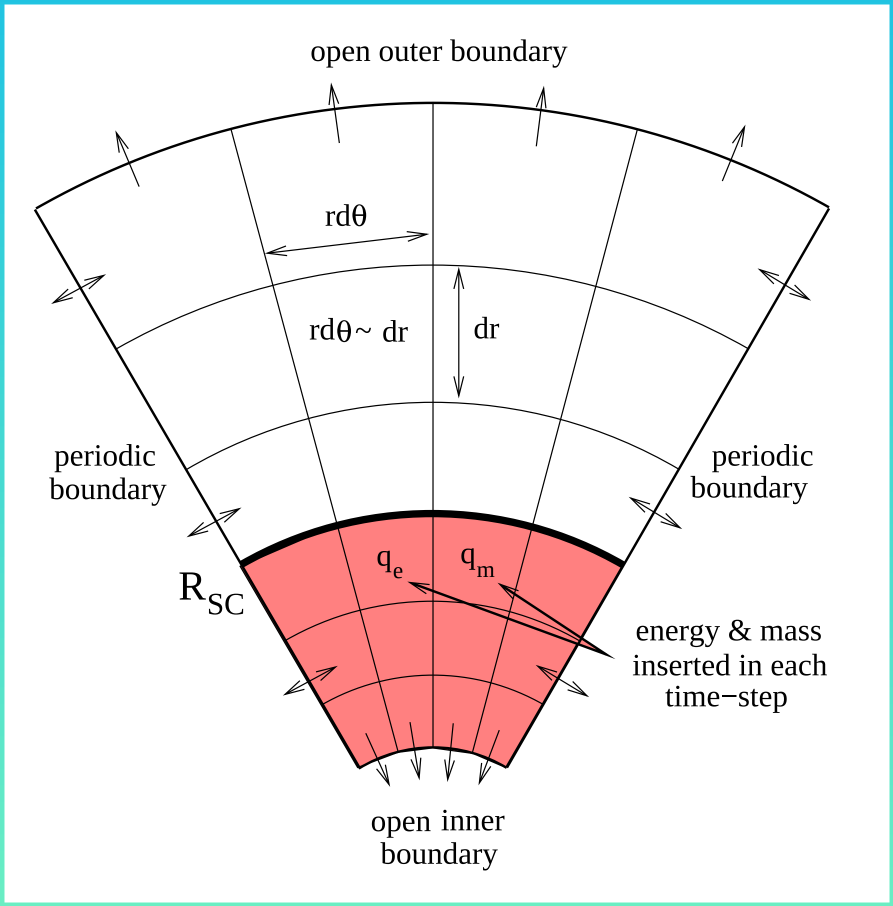


Physical model

Tenorio-Tagle et al. (2007)



Numerical model



- based on ZEUSv3.4.2

$$\frac{D\rho}{Dt} + \rho\nabla\cdot\mathbf{u} = q_m$$
$$\rho\frac{D\mathbf{u}}{dt} = -\nabla P - \rho\nabla\Phi - q_m\mathbf{u}$$
$$\rho\frac{D}{Dt}\left(\frac{e}{\rho}\right) = -P\nabla\cdot\mathbf{u} + q_e - Q$$

- cooling: $Q = n^2\Lambda(T,Z)$
  - *c. f. by* Plewa (1995)
  - *time-step controlled by cooling*

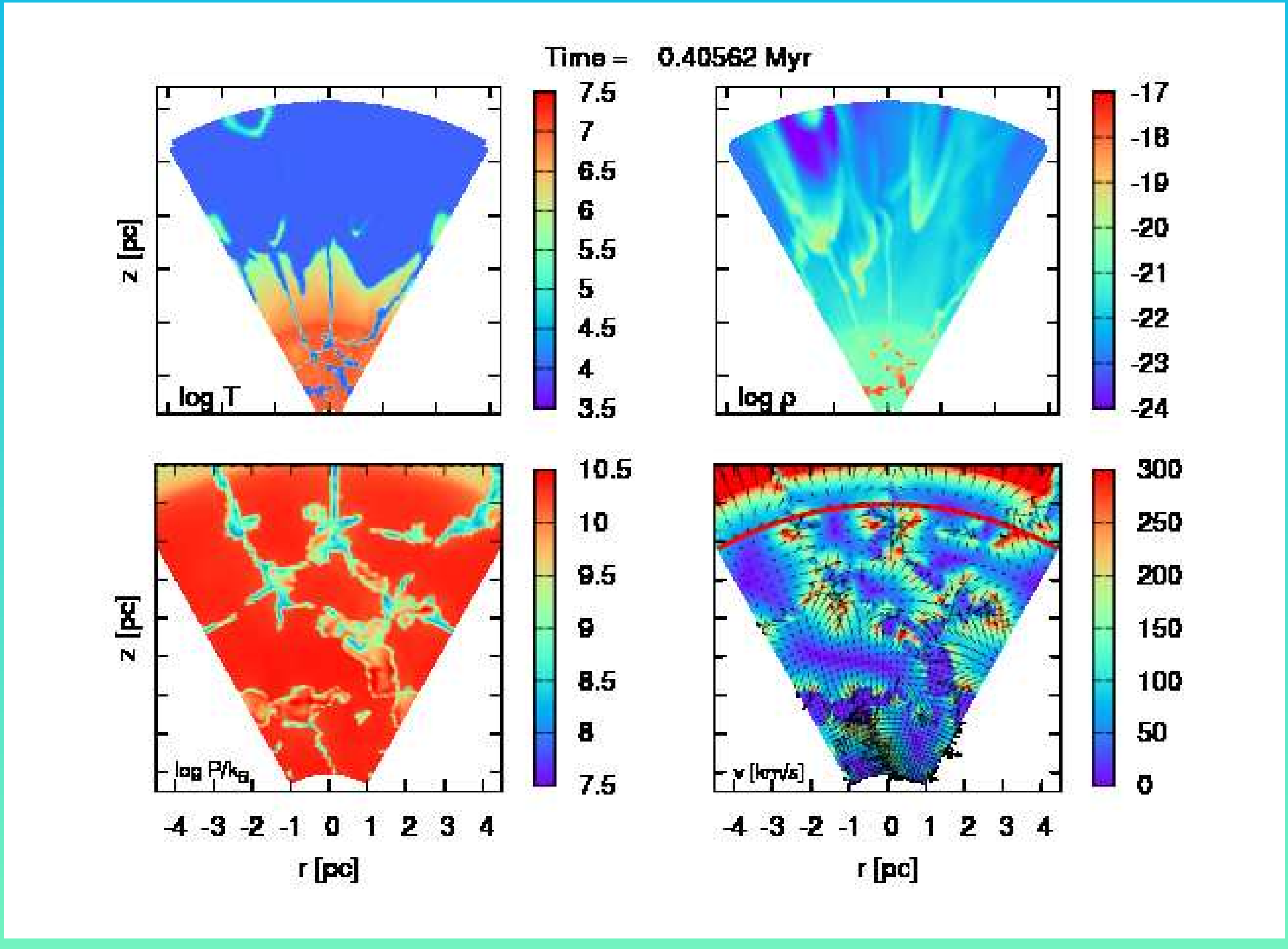
$$dt_{\mathrm{cool}} = \varepsilon\tau_{\mathrm{cool}} = \varepsilon\left|\frac{e}{\frac{de}{dt}\big|_{\mathrm{cool}}}\right|$$

  - $\tau_{\mathrm{cool}} \ll \tau_{\mathrm{HD}} \quad \rightarrow$ *substeps*

- heating
  - *gas is not allowed to cool below* $T_{\mathrm{lim}} = 10^4$ *K (heating)* $T_{\mathrm{lim}} = 10^2$ *K (no heating, M12, M13)*

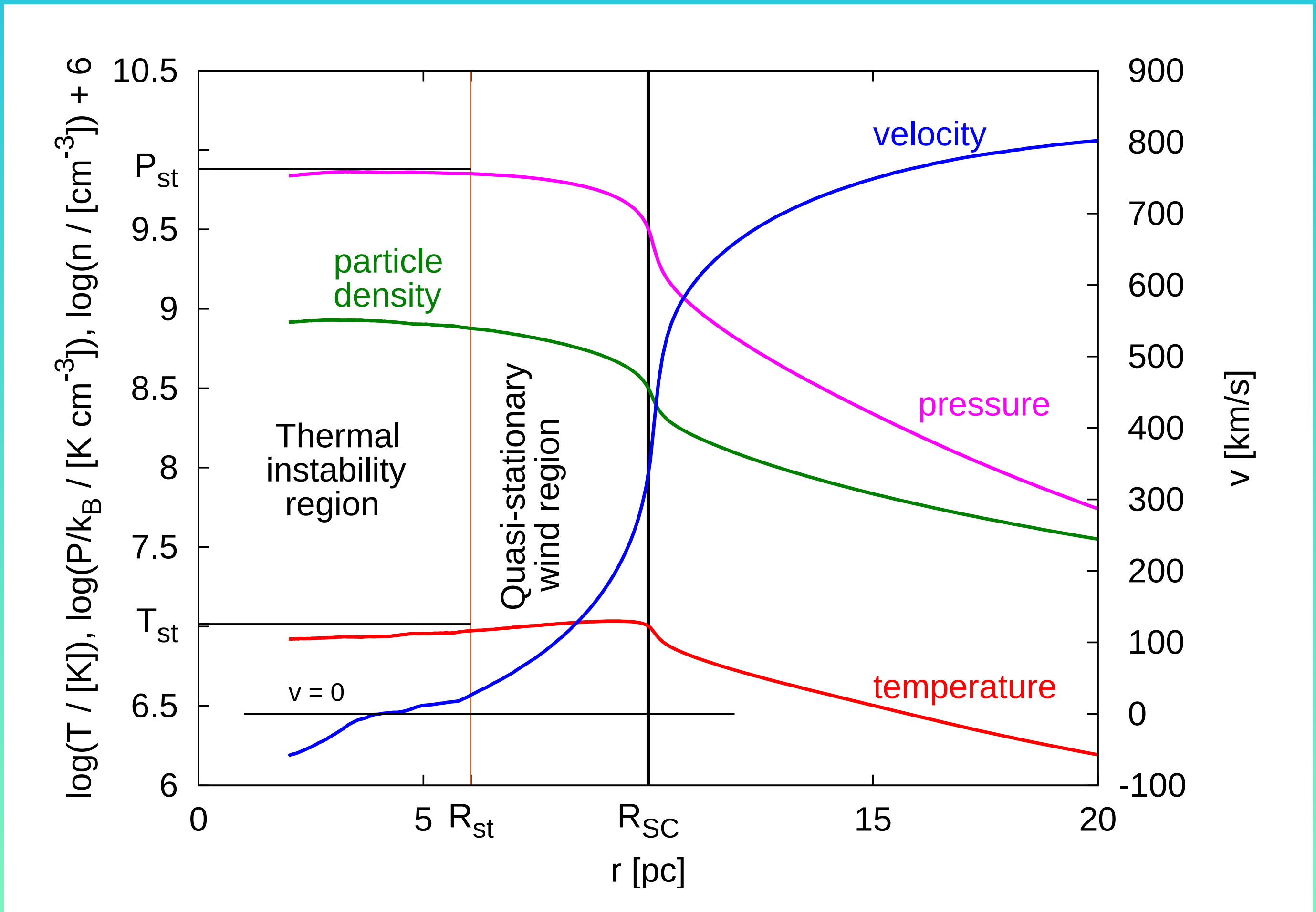
Example simulation

- Model 5: $R_{SC} = 10$ pc, $L_{SC}/L_{\rm crit} = 20$, $\eta = 1.0$, 600×224



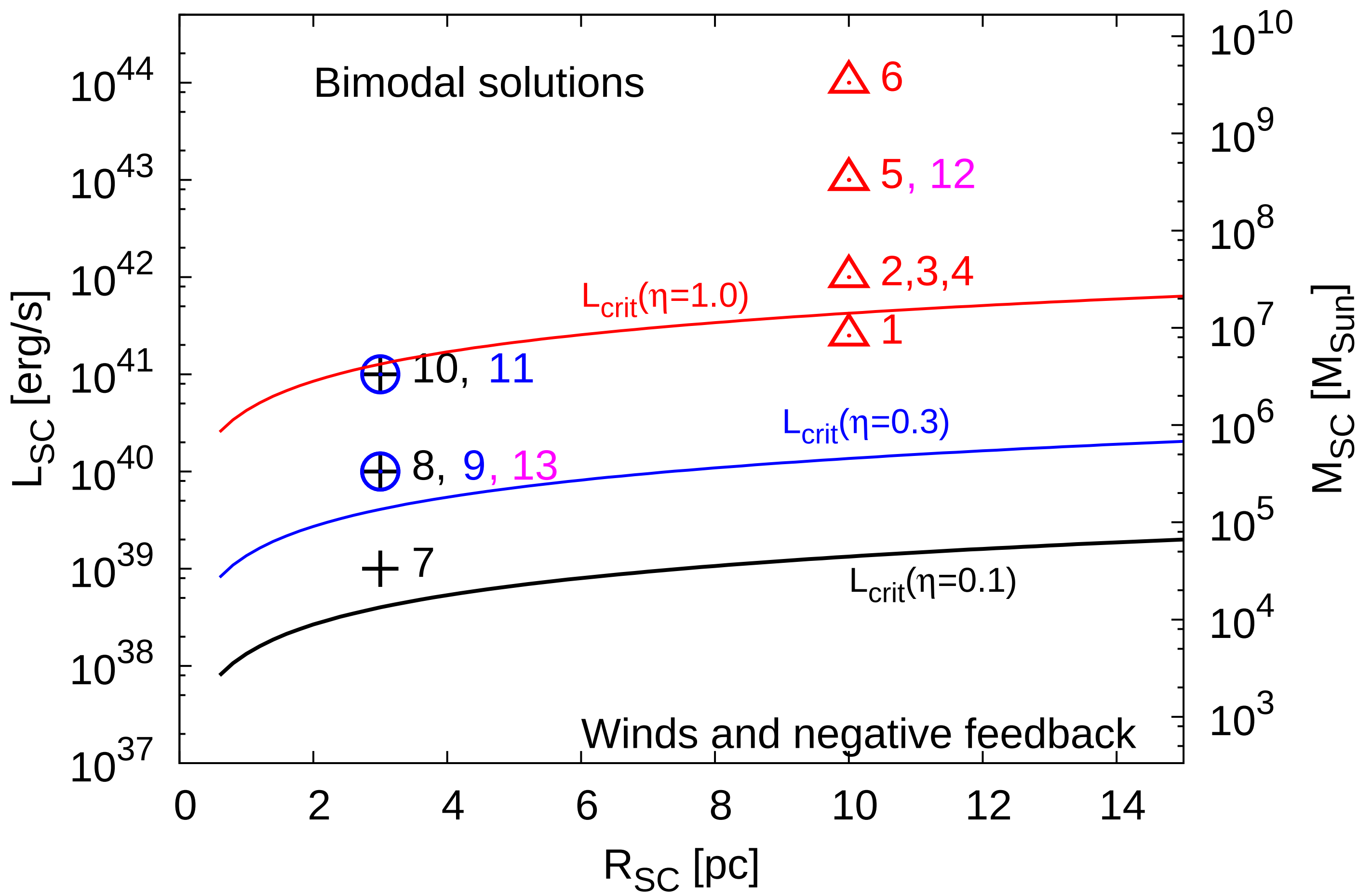
Internal structure of SSC in bimodal regime

- radial profiles averaged over θ and $t = 0.4 - 0.8$ Myr
- $v = 0$ slightly below R_{st} (due to passing clumps)
- $P = \mathrm{const}$ for $r < R_{st}$ (in agreement with semi-anl. value)



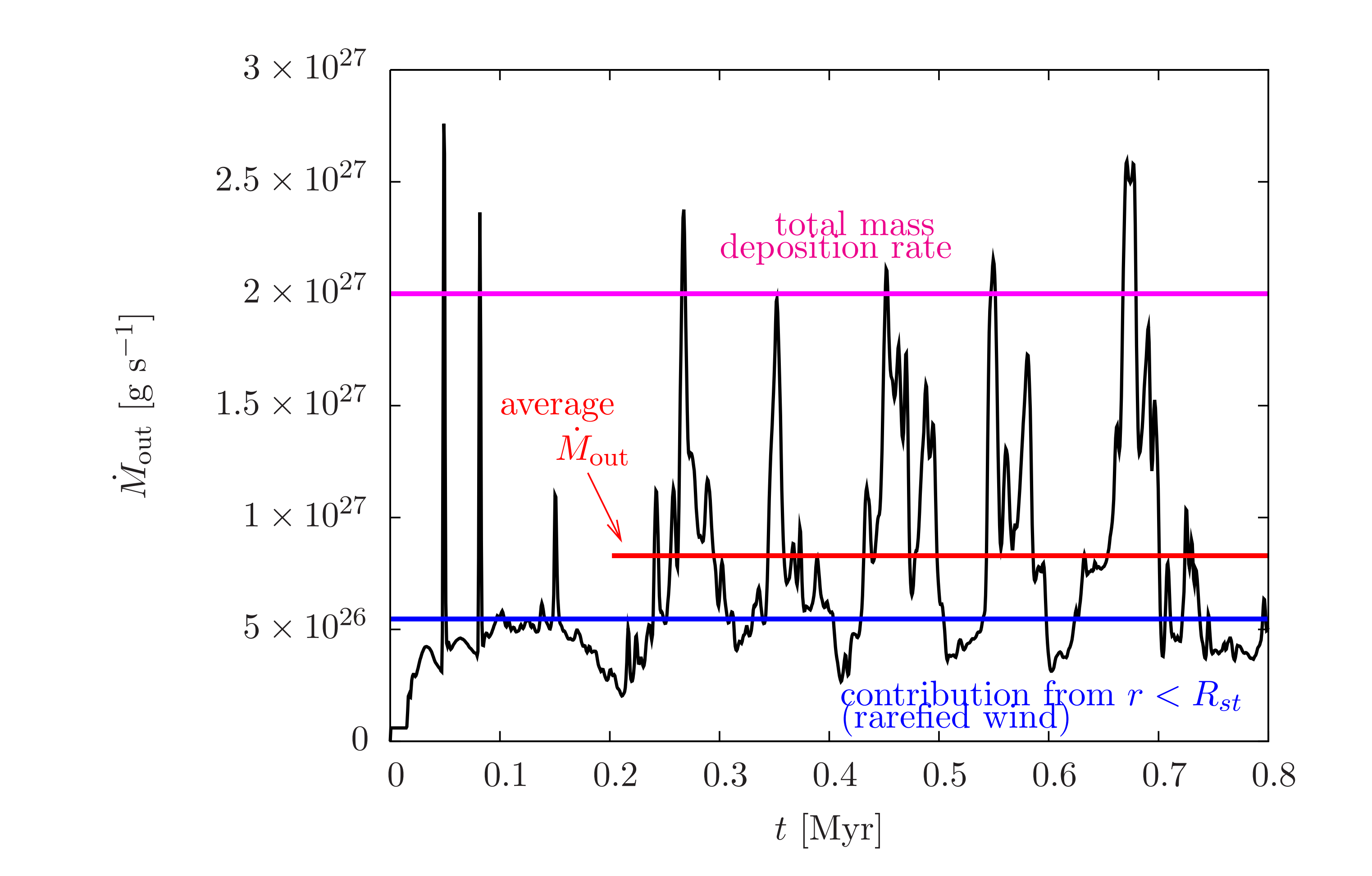
Set of computed models

- $R_{SC} = 3, 10$ pc, $L_{SC}/L_{\rm crit} \sim 0.5, 2, 20, 200$, $\eta = 0.1, 0.3, 1.0$
- $T_{\rm lim} = 10^4, 10^2$ K, grid: 150×56, 300×112, 600×224

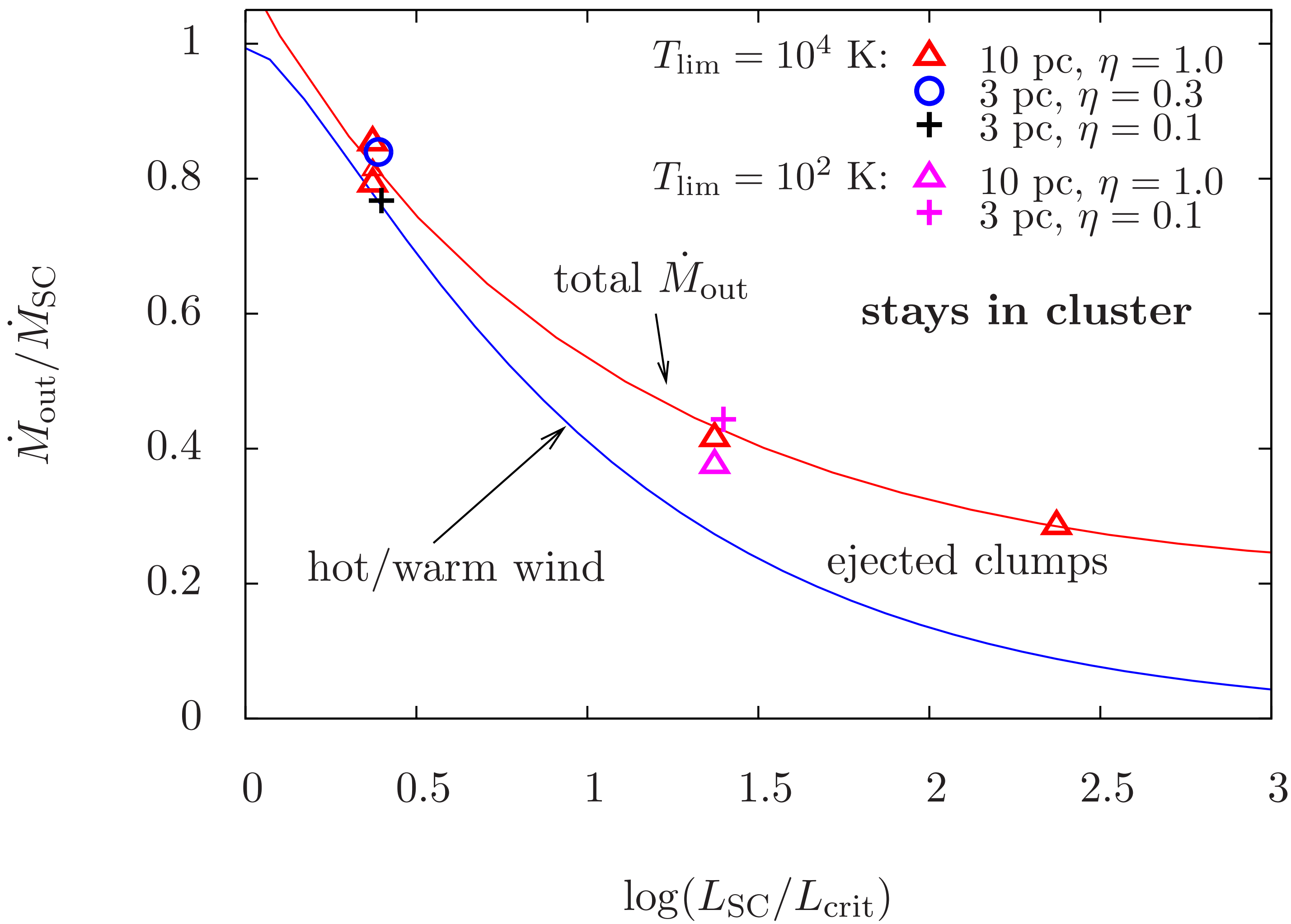


Outflow from the cluster as a function of time

- two component outflow: 1. rarefied originaly hot wind
  2. dense clumps



Outflow from the cluster for different models



Conclusions

- 2D simulations confirm bimodal behaviour
  - ▷ *outer quasi-stationary wind region*
  - ▷ *inner thermal instability region*

- two-component outflow:
  - ▷ *dense warm ($\sim 10^4$ K) clumps*
  - ▷ *rarefied wind (originally hot, cooled down at a certain distance from the cluster)*

- $L_{SC}/L_{\rm crit}$ is the essential parameter
  - ▷ *determines R_{st} $\Rightarrow$ relative amount of mass in the two components*

- most of mass inserted below R_{st} stays inside the cluster $\rightarrow$ SF

- η another important parameter
  - ▷ *determines T of the hot medium in the central region*
    $\rightarrow$ velocity of repressurizing shocks, recombination line-width

Future

- calculation of line-profiles from simulations
- model of star formation
- 3D model based on the MPI parallel code Flash

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References

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